Compact Meander Line Telemetry Antenna for Implantable Pacemaker Applications

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ABSTRACT

The demand for health technology is increasing rapidly especially in telemetry applications. These applications generally use implanted antennas to be utilized for data transfer from patients to another reader device. This procedure can make the health care more efficient, since it provides fast diagnosis and treatment to the patient. This work presents a design of telemetry antenna to be used in Pacemaker application in Medical Implant Communication Services (MICS) (401 MHz-406 MHz). By introducing Compact Meander Line Telemetry Antenna (CMLTA), length (L_s) and width (W_s) of substrate have been reduced by 36.84% and 40% respectively. The proposed antenna offers advantages of easy fabrications, low cost and light weight with a 133 MHz bandwidth.

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1. INTRODUCTION

An active medical implanted device offers a very effective and precise medical treatment for specific disease [1]. The most popular active implanted medical devices nowadays are cardiac pacemaker due to an increase in heart problems [2]. In order to provide very efficient treatment using pacemaker, telemetry antennas to be used in pacemaker have been developed. By using telemetry antenna, communication between pacemaker and other devices can be done to observe the level of patient conditions [3].

The capabilities of antenna performance for health care, radio communications and monitoring have become major concern for designing high performance antennas. The telemetry antenna offers number of advantages including flexibility and can directly communicate with other devices [4]-[5]. Various telemetry antenna designs have been proposed by several researchers. The requirements include compact size, wider bandwidth, radiation efficiency and the most importantly the patient safety [6]-[7]. Miniaturization is one of the important parameters to design a telemetry antenna especially for biomedical devices [2]. Moreover, low frequency is very crucial and need very specific technique to obtain small size for optimization of the antenna. A review of implantable antennas for health applications and biomedical telemetry has been provided in [4]. Hybrid patch/slot implantable antenna was designed for MICS. In [8], a hybrid patch antenna has been proposed by embedding the meander slot and six open slots in the ground which offers effective size reductions at a fixed operation. Previous researcher has proposed implantable antenna to be utilized in MICS band by using expensive dielectric substrate and superstrate such as Rogers R03210/RO3010 [9].

MICS band is the most commonly used frequency for implanted antenna, which is allocated by MICS for biotelemetry applications according to Recommendations of ITU-R SA.1346 and later superseded by RS.1346 [9]. However, the band 401- 406 MHz is previously allocated to the Meteorologically Aids Service. Therefore, in order to reduce the harmful interference that might occur to the operations of Meteorologically Aids Service, a maximum limit of -16 dBm for the effective isotropically radiated power of MICS is specified [10]-[11].

Moreover, frequency ranges for wireless power transmission into human tissues have been investigated in order to observe the effect on the human body. In order to realize the CMLTA effect on human body, CMLTA is placed in the body model consisting of different tissues such as muscle, skin and fat (non-homogenous). The dielectric properties at 402.5 MHz for these tissues are shown in Table 1. In order to observe the effect of skin thickness, variations of thickness also have investigated. Based on previous work, for efficient modelling, one layer skin model (homogenous) can also be used for implantable antenna design [12].

Table 1. Dielectric properties of muscle, fat and skin at 402.5 MHz

Tissues	Relative permittivity (ε_r)	Tangent loss (σ) S/m
Muscle	58.79	0.84
Fat	5.57	0.04
Skin	46.72	0.69

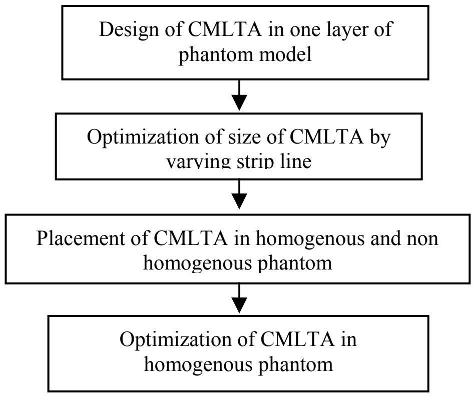

Figure 1. Design flow of the proposed CMLTA

In this paper, Compact Meander Line Telemetry Antenna (CMLTA) is proposed as shown in Figure 1. A CMLTA is designed based on modification and optimization of basic meander line antenna. By properly employing compact meander on the patch, the current path can be lengthened for the proposed antenna which lowering the antenna resonant frequency. Moreover, the proposed CMLTA can provide wide bandwidth and compact antenna size for pacemaker applications. Details of the antenna design are provided and discussed in the following section. In addition, comparison between CMLTA designs in homogenous and non-homogenous body models has been carried out to observe the effect on return loss performances. Moreover, the optimization of size of CMLTA has been done in homogenous phantom.

2. RESEARCH METHOD

The investigations have been carried out in order to obtain the optimum size of the telemetry antenna. The investigation begins by introducing Compact Meander Line Telemetry Antenna (CMLTA) to be resonated at 402.5 MHz. In this work, CMLTA has been designed using 3.2 mm thick FR-4 (ε_r = 4.7 and $tan\ \delta$ =0.025) as dielectric substrate and superstrate. For this design, commercially available CST computer model was used to model CMLTA.

In this work, the proposed antenna is examined with human body tissues in order to observe the effect of human body on the antenna proposed antenna performance. Therefore, the CMLTA has been designed with substrate and superstrate layers. The superstrate is capable of protecting neighboring tissues surrounding the proposed antenna. The superstrate layer acts as buffer between the metal radiator and human tissues by reducing Radio Frequency (RF) power at the locations of lossy human tissues. Moreover, by employing the superstrate layer, the antenna can be assuredly matched to 50 Ω through decreasing effects of the high conductive biological tissues [15]. Transmission line and compact meander element have been used to achieve smaller dimension as compared to a conventional microstrip patch antenna [13]. The CMLTA design is shown in Figure 2.

Moreover, the variation of strip line, t_s has been carried out in order to get the optimum size of the CMLTA. The comparative results are provided in Results and Analysis sections. Based on the human body which consists of different layers of skin, fat and muscle tissues, as shown in Figure 3, the phantom box can also be created with single layer [2]. As shown in Figure 3, the gap between the compact loop antennas and outside is 4 mm which is considered in the design as estimated skin thickness.

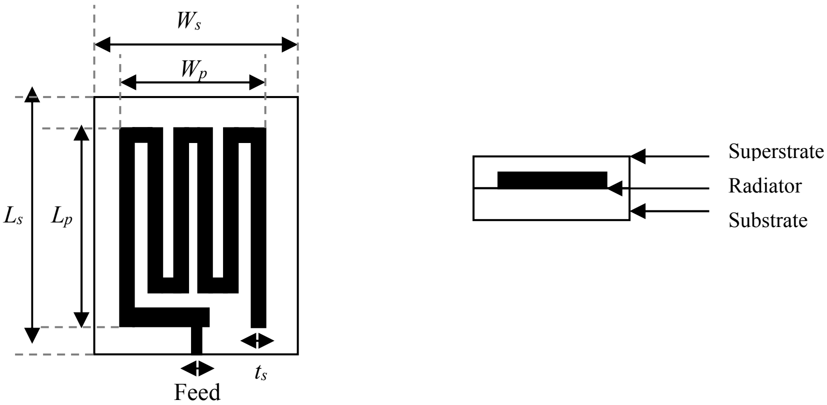

Figure 2. Detail design configuration of the CMLTA for telemetry applications L_s= 21.02 mm, W_s=3 0.5 mm, L_p=15.01 mm, W_p=26.5 mm, t_s=3.63, w_t=1 mm)

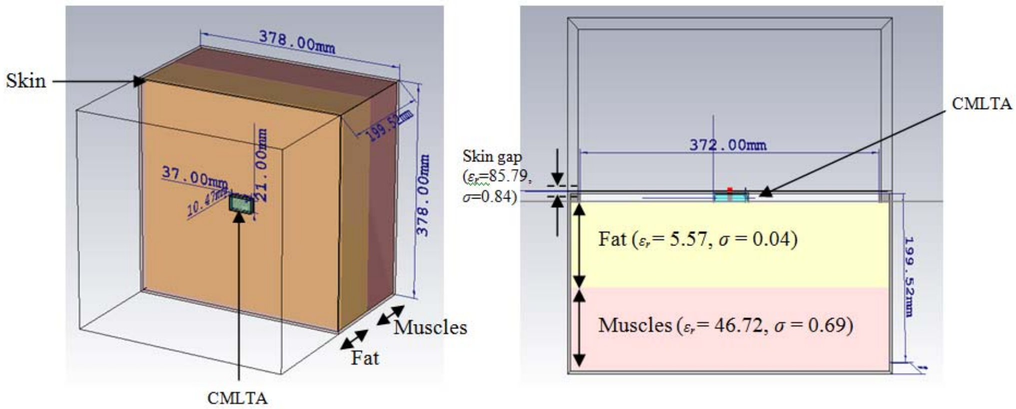

Figure 3. Multilayer human body phantom at 402.5 MHz. (a) Perspective view (b) Side view

3. RESULTS AND ANALYSIS

The variation of strip line, t_s has been carried out in order to obtain the desired resonant frequency with optimized CMLTA. The results are shown in Figure 4 and detailed summary is provided in Table 2.

Table 2. CMLTA performance due to strip line variations

Variation of Strip line (mm)	Dimension (mm)		Frequency Range	% Bandwidth
	W_p	l_p	(MHz)	
2.5	40	43.8	322.8 - 449.7	31.5
3.0	40	43.0	320.7 - 453.7	33.0
3.6	40	42.0	326.2 - 453	33.5
4.0	41	42.5	326.2 - 453.7	31.5

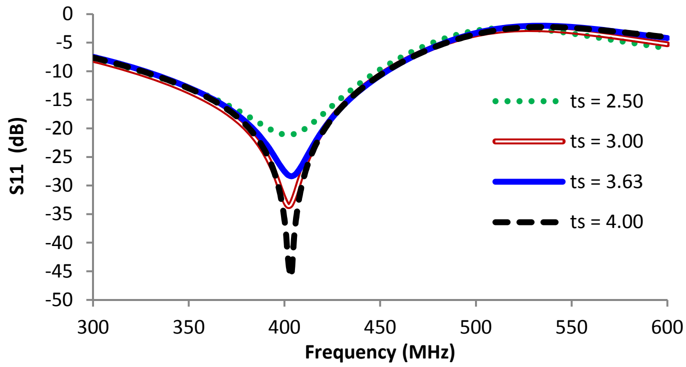

Figure 4. Variation of size strip size of Compact Meander Line Telemetry Antenna

As depicted in Figure 4, different size of strip line for CMLTA affects the return loss performances. From the results shown in Table 2, it can be observed that by using strip line of 3.6 mm higher bandwidth of 33.5% can be achieved as compared to strip line of 2.5, 3.0 and 4.0 mm. It is because for the proposed design configuration, the surface currents travel long distance inside the loop. Therefore the electrical dimension of the patch element elongates and provides an opportunity to design a patch at the same resonant frequency of 402.5 MHz with compact physical dimensions. In order to elaborate this phenomenon surface current distributions and electric field intensity have been generated using CST MWS simulations as shown in Figure 5. It is shown that the maximum surface current occurs in the center of the meander antenna when the electric field is excited in the Y-direction. By introducing compact meander line antenna, it is shown that the surface current density (*J*) and electric field intensity (*E*), the dimension of the antenna can be reduced. The increase in the surface current density (*J*) on the conducting material causes an increase in the electric field intensity *(E)* which is given by Maxwell Equation 1.

$$\nabla \times H = J + J\omega\varepsilon E \tag{1}$$

Where (*H*) is magnetic field intensity and (*J*) is current density through the surface reflectarray element. The current density (*J*) can be correlated to electric field intensity (*E*) and conductivity, (σ) of conductor material which is given in Equation 2.

$$J = \sigma E \tag{2}$$

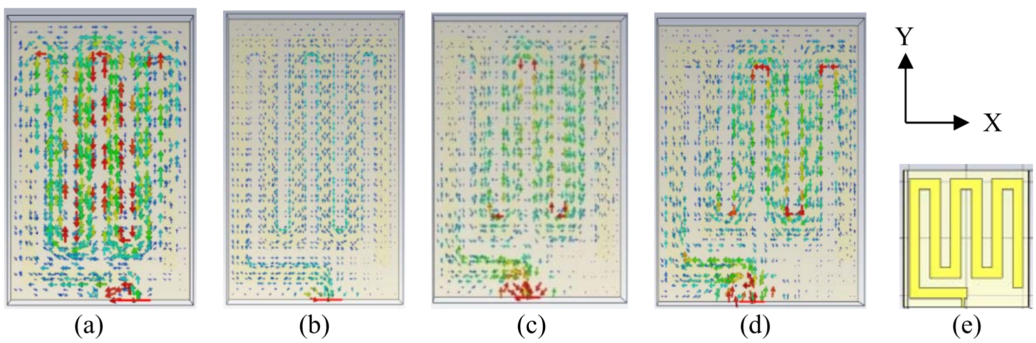

Figure 5. Surface current distribution on the proposed CMTLA. (a) t_s=2.5mm, (b) t_s=3.0mm, (c) t_s=3.63mm (d) t_s=4.0mm, (e) Antenna orientation

As mentioned earlier, the telemetry antenna has been examined by embedding it in fat, muscle and skin layer. In order to investigate the effect of the skin thickness, detailed analysis by variation of skin thickness has been carried out. The skin thickness was varied from 1 mm to 5 mm and the effect of variation on the return loss and absorbed power were observed as shown in Figure 6 and Table 3 respectively.

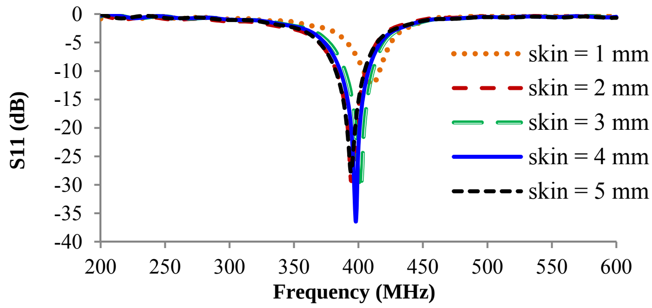

Figure 6. Return loss for different thickness skin

Table 3. Absorbed power by placing antennas under different skin thicknesses

Skin thickness (mm)	Power Absorbed (W)
1	0.916337
2	0.910852
3	0.999572
4	0.935055
5	0.836095

From Figure 6 it can be observed that the skin thickness has a significant effect on the antenna return loss and resonant frequency. The resonant frequency varies with a change in the skin thickness due to the coupling effect and the skin thickness of 1 mm offer high of return loss of -10.89 dB as compared to skin thickness of 5 mm which offers -25.12 dB of return loss. This is due to the coupling effect between antenna and thickness of skin layer. The absorbed power using different skin thickness has also been investigated in this work. The results are shown in Table 3. It can be observed that for skin thickness of 5 mm lesser power is absorbed as compared to skin thickness of 1 mm. From these results, it can be concluded that the thickness of skin can has a significant effect on the resonant frequency, return loss as well as the absorbed power. Therefore the placement of a telemetry antenna inside the human body is crucial and detailed analysis is needed to be carried out based on the requirements of the specific applications.

On the other hand, telemetry antenna has been located in a phantom with three different biological tissues (non homogenous model) as described earlier in Figure 3. The CMLTA in non-homogeneous human body model was compared with CMLTA placed in homogeneous body model in order to observe the effect of body tissues on the antenna performance. For homogenous body model, the properties used for phantom are (ε_r = 5.67, σ = 0.94 S/M and *tan* δ = 0.74). Figure 7 show the comparison of return loss between the two body models before and after optimization respectively. The tabulated data is provided in Table 4.

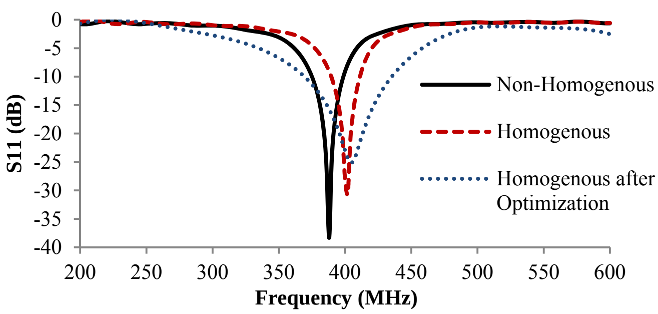

Figure 7. Comparison of return loss after optimization between homogenous and non-homogenous

It can be observed from Table 4 that both non-homogeneous and homogenous models provide a good agreement for the return loss performances while the bandwidth is slightly improved in the case of homogeneous model. This is due to the tissue properties used for the design. However the non-homogeneous phantom model is expected to provide comparatively closer results to the measurements because detailed tissue properties were used in this case.

Table 4. The performance of CMLTA after optimization

Model	W_s (mm)	I_s (mm)	Frequency Range (MHz)	Percentage of Bandwidth (%)
Homogenous	34	26.125	389.77- 414.39	6.17
Non-Homogenous	34	27	389.56- 411.19	5.37

4. CONCLUSION

By introducing the proposed CMLTA design, the dimension of the antenna can be minimized by 36.84% and 40% for length (L_p) and widths (W_p) of substrate respectively. Variation of skin thickness can also affect the performance of the antenna while homogenous and non-homogenous human body models provide almost identical results. Therefore simplified homogeneous body model can be applied for reducing the complexity in the design. Moreover, the proposed CMLTA can be used for telemetry application especially in biomedical applications. The CMLTA can be further investigated for realization of pacemaker inside the human body model for Electromagnetic Interference (EMI) and Specific Absorption Rate (SAR).

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